JRC Scientific and Technical Reports

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Support to the implementation, harmonization and further development of the Eurocodes

E. Gutiérrez, S. Dimova, A. Pinto

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For the European Composites Industry Association: Volker Fritz, Gustaaf Bos.

Additional comments on this proposal were sent in by Neil Loudon of the Highways Agency (UK).

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In addition to the data retrieval and analysis prepared by the JRC, this report is a compendium of meetings of the FRP ad-hoc working group in June and November 2005, followed by individual discussions and exchanges of technical notes with the organizations and representatives mentioned above. Their citation herein, at present, purports only to be an acknowledgement, on behalf of the ELSA Unit, of their contribution and interest in the potential for code development for FRP composites.

Summary

The scope of this document concerns the purpose and justification for a new Eurocode for fibre-reinforced polymer (FRP) composite materials, outlining the specific aims and reasons for standardization in this area, and the main interested parties (industry, consumers, trade, standardisation authorities and distributors) who will benefit from it.

In order to promote the realisation of construction works with FRP materials, and the perceived immediacy for a design code pertinent to them, this proposal considers the timeliness of the Eurocode in view of the available technology.

In view of the importance of the construction industry in the European market, this proposal examines the potential benefits of the new Eurocode, or conversely, the detriments were it not to be implemented. Moreover, given the number of construction works currently using FRP materials without the availability of a standard design code, this proposal considers the urgency with which it is required.

Finally, it provides a tentative proposal for the consultation, feasibility analysis and initiation strategies.

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1 Rational and Policy Context

This proposal is motivated by the expanding use of FRP composite materials (or simply, *composites*) in the construction sector and the lack of an applicable set of European-wide design rules. Within the context of trade between EU Member States, the ever-increasing marketing of these materials sets the background for the need of a concerted EU effort.

The safe implementation of FRP composites and the need to promote the competitiveness of this emerging industrial sector are the main drivers quoted by representatives from the European construction associations. No less important, however, is the need for Europe to maintain a high level of technical proficiency, if it is to match the efforts of its main competitors from America and Asia. Based on their experience of using FRP composites in their own markets, leading EU industries are finding new markets outside of Europe, but, more often than not, their potential customers stipulate the need to back up their designs with internationally recognised codes. This cannot be left to market forces alone, but requires a coordinated effort by industry, certification bodies and academia under the aegis of a European-wide regulatory authority.

The policy context of this proposal is set within the framework of the EU Construction Products Directive-89/106/EEC and, more specifically, the Guidance Paper L which will be discussed in the following Sections of this proposal.

In regard of the Commission Recommendation 2003/887/EC on the implementation and use of Eurocodes for construction works and structural construction products, the following proposal addresses Recommendation No 6 wherein it is stated *'Member States should undertake research to facilitate the integration into Eurocodes of the latest developments in scientific and technological knowledge. Member states should pool the national funding available for such research so that it can be used at Community level to contribute to the existing technical and scientific resources for research within the Commission, in cooperation with the Joint Research Centre, thus ensuring an ongoing increased level of protection of buildings and civil works, specifically as regards the resistance of structures to earthquakes and fire'.*

Having regard for said Recommendation, the JRC, in cooperation with representatives from Industry, Certification Bodies and Research Centres from Member States, proposes that the Commission should endeavour to expand the current series of Eurocodes with the addition of a new Eurocode to provide a method for calculating the mechanical strength of elements consisting entirely, or in part, of FRP composites, which play a structural role in construction works.

The scope of this document concerns the purpose and justification for a new Eurocode for fibre-reinforced polymer (FRP) composite materials, outlining the specific aims and reasons for standardization in this area, and the main interested parties (industry, consumers, trade, standardisation authorities and distributors) who will benefit from it.

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2 Benefits with Respect to Guidance Paper L Section 1.1.3

With regard to guidance paper L concerning the Construction products Directive - 89/106/EEC, and in view of Part 1: General, the new Eurocode should aim to comply with the aims and benefits of the Eurocode programme. Specifically in Section 1.1.3:

- *Provide common design criteria and methods to fulfil the specified requirements for mechanical resistance, stability and resistance to fire, including aspects of durability and economy*.

The new Eurocode will address this point explicitly. Currently in Europe there are no common design criteria for the design of load-bearing structures using FRP. The current status in Europe is that structural engineers, architects and engineering consultancies are heavily dependent on FRP composite manufacturer's specifications and guidelines. The highly orthotropic properties of FRP materials inhibit civil engineers from using them because they do not see themselves as materials specialists. The new Eurocode will bridge this gap by providing prescriptive design criteria and methods for the definition of key mechanical, fire and environmental properties of FRP materials used in the construction sector.

- *Provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products.*

It is often the case that the production of these materials is based on patented technologies that do not allow flexibility within the more open, competitive-bid, market of the construction sector. This inhibits the structural design process and is aggravated by the lack of inability to interchange manufacturers' products. The construction sector does not rely on propriety construction items as this limits the contractor in the selection of components. The new Eurocode will provide a common basis for contractors to compare pricing for nominal constructions products that conform to specific structural capacity and function, and promote a more competitive market for their products in the construction sector. As regards structural reliability, it will provide a common approach, similar to that of traditional materials, and will enhance the selection processes for designers when choosing widely-differing construction materials.

- *Facilitate the exchange of construction services between Members States.*

Currently the FRP manufacturing and supplier community is highly diversified. There are many organizations purporting to represent the FRP production industry. Although many of their products confirm to ISO and related standards, the FRP industry is currently not geared towards the construction sector. The new Eurocode will facilitate the exchange in construction services by providing a common basis for materials production and design specifically geared towards construction products.

- *Facilitate the marketing and use of structural components and kits in Members States*.

Although the FRP industry is highly diversified, producers have tended to concentrate in specific niche markets; sometimes, expertise of certain manufacturing processes has very restricted markets. The construction sector is quite often not familiar with the range of manufacturing methods available for the construction of structural components or kits. A common basis for comparison of basic FRP structural components and materials is therefore required. The new Eurocode will provide methods to access the declared values in CE marking for structural products and kits.

- *Facilitate the marketing and use of materials and constituent products, the properties of which enter into design calculations, in Members States.*

With the sole exception of pultruded FRP profiles, none of the other FRP manufacturing associations have attempted to market their products towards the construction sector. The new Eurocode will provide designers with guidelines on the most appropriate process for construction kits and so motivate the marketing of FRP products and kits. The new Eurocode will provide liaison with other CEN technical Committees and EOTA working groups for harmonisation, especially with the Technical Committees and working groups producing harmonised specifications (hEN and ETA guidelines/ETAs) and decision rules that can be referred to.

- *Be a common basis for research and development, in the construction sector.*

Consultations with the major European construction organisations —such as the European Construction Technology Platform— have highlighted the need for a common design standard for FRP materials. The present lack of such standards at national level motivates the need to implement standards from a common basis. The extra costs due to replication, if each individual Member State would have to accrue if starting such a process from a low common denominator, would be reduced. The current climate towards EU-wide harmonisation within the present EUROCODE family precludes replication of code development at single Member State level.

- *Allow the preparation of common design aids and software.*

The subject of common design software for FRP design is brought to the forefront by the need of civil engineers to be able to design structural solutions using FRPs, a material for which most practising engineers have yet to develop a feeling for. A number of FRP systems producers have sought to take advantage of this opportunity by providing simplified design software as part of their materials package. Such software “design codes’’ have not been extensively calibrated and are usually biased towards a given company’s product kits. This area is therefore in drastic need of harmonisation and verification by extensive European, certification and R&D groups. A new code would, therefore, provide the essential design platform for design aids and software.

- *Increase the competitiveness of the European civil engineering firms, contractors, designers and product manufacturers in their world-wide activities.*

The European construction sector not only relies on its internal market, but must compete globally in many prestigious projects. As the application of FRP materials in the construction sector grows in Europe, USA and Japan, structural solutions using these materials are also being taken up in other global markets. Europe cannot lag behind in this part of the market. However, even within the internal EU market, the number of applications for FRP both in new structures, and their use as retrofitting systems for standard RC and steel structures is growing steadily. The European construction sector should not be technically handicapped by the lack of construction codes when wishing to use these materials: EU competitors may take their place.

3 Interested Parties

The context of this proposal within the framework of EU Commission policy has been presented above. That of the academic and research institutions will be dealt in subsequent sections. Here we identify the industrial parties and the executive agencies of standardisation authorities.

3.1 Regulatory Organisations

CEN-TC250: The Evolution group of CEN-TC250 is aware of the JRC initiative to prepare a document addressing the Purpose and justification for new codes and standards for FRPs in Civil Engineering. In fact, the Evolution Group (CEN-TC250 Chairman and other delegates) was briefed on the ad-hoc European group setup by the JRC to prepare the justification document. Furthermore, the Evolution Group has included in its position paper (covering the Maintenance, Promotion, Further Harmonization and further Development of the Eurocodes), a part on further-development where FRP composite structures are proposed as a work item.

European Organisation for Technical Approvals (EOTA): The dialogue between the JRC and EOTA, on the works for new codes and standards regarding the use of FRP composites in civil engineering, was initiated recently. It presupposes that the proposed standards of CEN/TC 250 are developed for two routes, namely:

- The route for designing composite products from their composite materials, by using laminate theory, with reference to existing harmonized, ENs for such materials and possibly ETAs for new materials.

- The route for design with prefabricated half finished products fabricated from constitutive materials, where the properties of such half-finished products (e.g. resistance of profiles) still need to be specified in future ETAs possibly on the basis of ETAGs, to be consistent with the design rules.

EOTA has shown interest in the subject and is prepared to assist in the following way:

- By cross-checking where demands for ETAs and related ETAGs exist already.

- EOTA will initiate the drafting of ETAs as technical specifications for prefabricated half-finished products if sufficient industrial interest (as expressed in the application paper "Purpose and justification for new codes and standards for Fibre-reinforced Composites in Civil Engineering") is also expressed for the preparation of these ETAs and this probably by preference on the basis of ETAGs to be drafted.

The works on design rules for fibre-reinforced Composites in civil engineering will also include work on rules for testing of prefabricated half-finished products that comply with the needs for design. Such rules for testing will be given to EOTA for further consideration (incorporation in possible ETAGs), and would then result in product properties, laid down in the individual ETAs, which would fit with the design needs as laid down in the design code(s)

Moreover, it might even be feasible to use the ETAG as and "experimental" codification basis, as long as the relevant Eurocode part is not yet drafted or finalised. For example in the area of metal anchors, the ETAG, which serves as basis for delivering ETAs in this area, contains an exemplary design annex, since at the time, there was no other European harmonised material (=code, standard?) available. This annex allows a designer to use the values of the individual products in a design of a work.

3.2 Industrial Organisations

The industrial sectors that will most benefit from this proposal are the European construction and composite materials industries. For this purpose the proposal will evolve with close participation from the European Construction Technology Platform (ECTP) and the European Composites Industry Association (EuCIA). Both organizations have been formally contacted by the JRC with a view to ensuring that their main concerns and needs are addressed by the proposed standard.

As regards the ECTP it is expected that the proposal will receive strong support in view of the fact that one of the so-called, Focus Areas, concerns the implementation of new materials and construction methods. Specifically the Materials Focus Area foresees that '*construction materials have an important role to play in sustainable development through their energy performance and durability, as this determines the energy demand of buildings through the lifetime*. *By developing the use of materials and their combinations, significant improvements of the environment and quality of life can be achieved. Together with the energy and the raw materials used during their manufacturing it becomes obvious that the production of building materials has a significant environmental impact due to the sheer quantities involved. Finally, these developments are needed to maintain and strengthen the competitiveness of European building materials producers and the entire construction sector*.' In this sense the role of FRPs in adressing key aspects of durability, as well as their potential to reduce net weight of structures, cut project development times in urban and transport renewal schemes, and the simplification of the logistics of design-to-site construction, fits well with the overall aims of the ECTP.

As regards the composites industry, the discussions so far with the secretariat of EuCIA have met with considerable interest. In the first place it seems apparent that there is a need for the European composites industry to be more aware of the impact that a new Eurocode, specifically tailored for FRPs, would have on their core business. To this effect the EuCIA has taken the opportunity of placing an advertisement in the November 2005 issue in the main industry journal 'Reinforced Plastics' requesting that companies involved in this sector should contact the EuCIA in order to express their views concerning the needs for a new Eurocode for FRPs in the construction sector. The journal article asks its readers if a new code is needed, why Eurocodes are important to the construction industry at large, why civil engineers want it and the specific points related to the composites industry, namely: the economic and legislative reasons why certain types of structures such as large wind turbine towers, bridges and other primary structures must conform to safe and trusted EU-wide building codes. The article also asks the industry in which manner it wishes to be represented in the drafting stages of the eventual code. Clearly the response received from the EuCIA will be of great value in assessing the needs and potential of FRPs for this industry.

4 Timeliness and Urgency

The most striking feature of the FRP industry is the range of available constituent materials, and their combination and manufacturing methods. This generates a high innovation potential, but is, at present, due to a lack of standards, problematic from the perspective of quality control and assurance: a product tested and characterized yesterday, may no longer exist today, even though its replacement looks identical and is marketed as the same product.

Similarly, production equipment and capital investments for production start-up are relatively small and typically handled by small and medium-sizes enterprises. This fact adds to the potential for problematic QA/QC and inconsistent production.

There are two main factors that drive the need for a new Eurocode for FRP materials. In the first place, as for any structural product, European citizens will expect appropriate levels of safety for structures manufactured from FRP composites. It is to be expected that these must be ensured within the context of harmonised and tested norms such as the Eurocode family. Secondly, in view of world-wide competition in the area of construction products, European industry's capacity to compete will be hampered if its products are not backed up by effective manufacturing and construction standards.

Both these aspects are analysed in turn below; however, it is first required to have an overview of the demand for these materials in terms of the number and type of structural applications and the trends over the past few years. This sets the background for the timeliness and urgency of a new FRP code.

4.1 Market Issues

4.1.1 The EU Perspective

Precise figures for the FRP market are difficult to come by, due to the FRP sector's high fragmentation. Moreover, data for this specific market is 'hidden' within data for the plastics sector as a whole, which is for both unfilled and filled plastic materials. The European Union's statistical data base, EUROSTAT, does not collect segregated figures for the FRP sector, but instead, combines them with the data for the plastics market. The same approach applies to analyses on the market conducted by the individual Member States. Thus, in a recent survey by the French Ministerial organisation Service des Ètudes et des Statistiques Industriels (SESSI, 2004)[1], itself based on EUROSTAT data, it is estimated that the FRP sector represents 5% (equivalent to 7 billion euro) of the total EU plastics market, which is estimated to be worth 140 billion euro.

These figures match those in a recent study by the UK's Department of Trade and Industry (DTI, 2001)[2]. Based on figures for 1998, the DTI estimated that the overall revenue for the FRP sector in the EU 15 was 5 billion euro, and that this value was expected to grow by 3.8%

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[1] http://www.industrie.gouv.fr/biblioth/docu/4pages/pdf/4p189-anglais.pdf)

[2] Department of Trade and Industry, UK Polymer Composites Sector: Foresight Study and Competitive analysis, October 2001. http://www.dti.gov.uk/

per annum. Based on this assumption the sector market turnover, in 2004, would be of the order of 6 billion euro, matching that figure obtained by the French Government. The DTI report states that the construction sector represents 21% of the total value. An FRP structural Eurocode would also be of commercial value to two other sectors. The industrial sector accounts for 10% of value (for example: pressure vessels, piping, chimney, chemical scrubbers chemical plant applications), and the transportation sectors another 32%. Together these three sectors, with a need for the code, account for nearly two-thirds of the total FRP market within the EU.

The report by SESSI highlights the finding that, between 1990 and 2001, the European market share for the worldwide export of plastics reduced from 62% to 48%, and over the same time period the Asian (particularly China) share of the same market had increased from 12% to 21%. To offset this loss in European market share the report suggests that further research to develop the exploitation of FRPs would offer the competitive advantage over other plastics materials processes that do not offer the same potential as FRPs to increase exports in terms of added value. That is, exploiting the EU's competitive edge in, research-based high-value FRP products.

In view of the fact that, in Europe, the building trade represents 30% of the FRP composite line (including plastics and other reinforcement substances), it is believed that FRPs will have an increasing use in the building industry, particularly when used in the main structure components that will enable new architectural shapes.

A number of organizations have been formed in Europe with the express interest in promoting the use of composites in construction; notably COBRAE (currently based in the Netherlands) and the Network Group for Composites in Construction (currently based in the UK). Although both these organizations have members from European Academic and Composites manufacturers associations (e.g. the European Composites Industry Association) their organization and funding cannot be compared to equivalent programmes currently running in the USA (of which more below). A larger European-wide umbrella organization clearly needs to be established in order to pool resources and target the needs of the European sector. An increased degree of funding to such organisations is required in order to make them more independent from the attentions of extra-EU FRP-producing organizations from the USA and Japan that have a direct stake in the FRP markets in their own countries, and who are looking to Europe to expand their sphere of influence.

4.1.2 The USA Perspective

In contrast to the fragmented economic data sets in Europe, the evolution of the FRP market in the USA can be seen in

Figure 1 where it is shown that the use of FRPs in the transportation and construction markets has grown substantially over the past four decades. Such figures serve to highlight the growing importance of the FRP market. These data are important to set the backdrop for policy and decision makers, both at US Federal and National levels, in order to gauge the future potential of these materials in key industrial sectors. Europe urgently needs substantiated data sets from its own market if the technical developments —encouraged in the EU over the past two decades— are to be consolidated into a competitive EU industry capable of facing to competition from the USA.

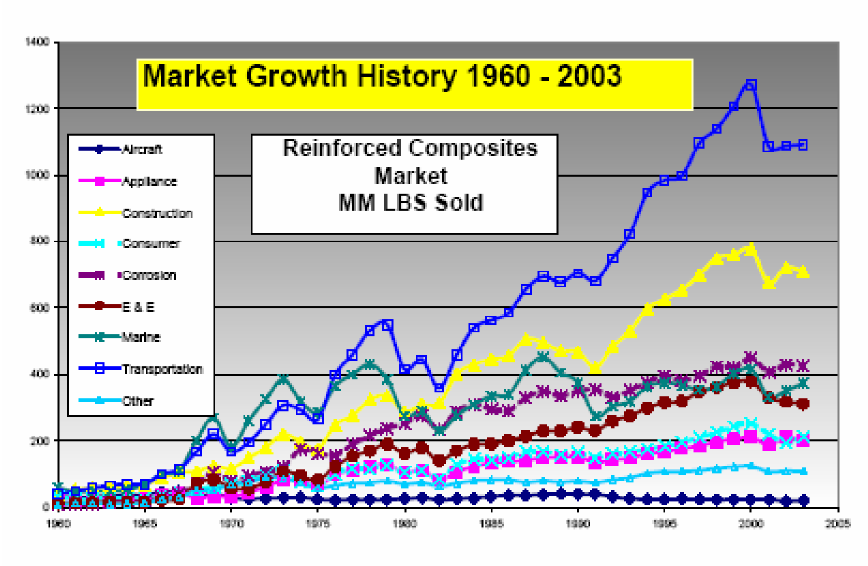

Figure 1 Evolution of FRP market share (source American Composites Manufacturing Association)

Further analysis of USA data and reports from Federal and Governmental sources reveals that, in the area of construction, the use of composites has benefited considerably from Federal R&D projects targeting the USA's need to refurbish its ageing highway infrastructure (a problem shared by most EU countries). A recent report by the National Cooperative Highway Research Program (NCHRP[3]), funded by the Transportation Research Board, discusses the finding of a study to develop a strategic plan for FRPs in the highway infrastructure. The extensive report is written as a white paper and discusses the following main key areas for successful FRP implementation:

- Repair and retrofitting
- FRP reinforcement (re-bars and tendons)
- Seismic retrofitting
- FRP bridge decks
- Unique applications

The report concludes that, apart from certain key technical aspects that still have to be evaluated (such as environmental and durability aspects), the main barrier preventing FRPs from becoming competitive are related to manufacturing costs, proper technical knowledge by practising civil engineers, and the lack of appropriate codes and standards.

The USA composites industry has faced many of the same problems that its European counterparts have had to deal with over the past two decades. However, the most significant difference vis-à-vis the EU, has been the significant R&D resources that have been pooled by Federal and State authorities, such as in the CALTRANS (California Department of Transportation) programme, into finding the best technical solutions for the uptake of FRPs in

[3] National Cooperative Highway Research program, Transportation Research Board of the National Academies, Report 503, Application of Fiber reinforced Polymer Composites to the Highway Infrastructure, Washington DC. 2003. http://www.trb.org/

the construction sector. In this sense the USA has a stronger overall technological foothold in this area compared to Europe; however, it is important to point out that leading R&D projects conducted in USA in this field were performed by European researchers who were able to find funding for projects which were relative cash-starved in the EU (this is particularly true for the last FP6).

In conjunction with a strong R&D environment the FRP industry in the USA has been quick to react to this potential market. A number of USA pultrusion companies now offer primary structural members consisting of large gauge hybrid (glass/carbon fibre) beams specifically designed for the bridge sector. Other companies have developed a number of solutions for bridge decks: an area where FRP materials are proving to be highly competitive with RC decks. Below we shall examine the effect this has had in the USA's share of the FRP bridge sector.

In conclusion, it can be said that in the USA the spin-offs from Federal and State funded R&D projects have resulted in a burgeoning FRP industry geared towards the construction sector that is, technically, in a position to compete with, and within, the EU market.

4.2 Competitiveness Issues: Status of World-Wide EU Share in the FRP Bridge Sector

Due to their strategic and symbolic importance, a review of the statistics on FRP bridge applications, worldwide, provides a useful barometer of Europe's status in this area. It is postulated herein that the current state of the art in bridge applications reflects (at least in percentile terms) the status of FRP applications in other areas such as building repair and retrofit where the use of FRPs is even more widespread. A complete catalogue of all FRP applications is outside the scope of this document; however, bridge applications have been noted and catalogued by a number of organizations. We have yet to find such an exhaustive catalogue for other implementations of FRP in the construction sector.

The analysis presented here is divided into pedestrian and vehicular bridges with data obtained from the American Composites Manufacturing Association (ACMA[4]) and the International Association for Bridge and Structural Engineering (IABSE[5]). The list is not exhaustive and runs only up till 2003. The records show that applications of FRP composites to bridge structures range from primary load-bearing applications (piers, trusses, decks, cable tendons and reinforcing bars), to secondary load bearing elements (gangways, guardrails).

The current status of the European industry's position vis-à-vis its main competitors is presented in terms of the main global trading blocks. Thus, the data sets group the output from EU and EFTA countries versus N. America (Canada and USA) and Asia and Oceania (China, Japan and Australia). For the purpose of completeness we have included a single application from S. America (Caribbean) in the pedestrian bridge sector.

The data sets used for this analysis contain information as to the year of construction, location, length, width, and the type of intervention (deck etc) and manufacturing organisation. In total 160 pedestrian and 175 vehicular bridge applications have been studied from the ACMA data set. Most records contain complete fields; however for a number of cases (seven pedestrian and four vehicular), neither the length nor the width of the application are given.

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[4] http://www.acmanet.org/

[5] International Association for Bridges and Structural Engineering, Use of Fibre Reinforced Polymers in Bridge Construction, Thomas Keller, ISBN 3-85748-108-0, Switzerland, 2003.

In Figure 2 and Figure 3 the evolution of the number of bridge applications of pedestrian and vehicular bridges are reported. In both cases it can be seen that the growth rate has been exponential, and, as expected, vehicular bridges started to appear after pedestrian applications. It is notable that the growth rate in vehicular bridges, if anything, is higher than that of pedestrian ones: by the turn of the last century, more vehicular than pedestrian bridges were built using FRP components. This is a very fast take-up, considering the more stringent stiffness and strength criteria required for vehicular structures.

In **Figure 4** and **Figure 5** are shown schematic representations of the number of worldwide bridge applications up till 2003. Each circle represents a bridge and the size of the circles is scaled to represent the length. From these it can be seen that the N. American sector dominates both the total number and cumulative length of bridges built in both the vehicular and pedestrian cases. Moreover, it can be said that the technology and system providers are essentially from the USA; but, whereas the pedestrian bridge sector is dominated by a E.T. Techtonics (PA) (a company that markets itself exclusively as an FRP bridge manufacturer), vehicular bridges are not dominated by a single company, although Hardcore Composites, Martin Marietta, Creative Pultrusions and Kansas Structural Composites take the major share.

The leadership of the N. American in the FRP sector is clearly demonstrated in **Figure 6** and Figure 7, from where it can be seen that the N. American region (essentially USA), comprises over 80% of vehicular bridge market and nearly 50% of the pedestrian bridge sector.

There are many reasons why the USA sector has shot ahead of both the European and East Asian markets; but a lack of technology in the EU region is not the primary cause. There are many FRP industries in Europe that are capable of providing quality FRP kits and products for the construction sector, however what has been lacking in Europe and the Asian regions, has been the massive Federal programmes geared to implementing FRP technology for structural rehabilitation; particularly in the seismic and bridge rehabilitation programmes. In parallel with the expenditure in R&D, most of these programmes have been tagged to normative and pre-normative guidelines for application of FRPs in construction. The CALTRANS and AASHTO (American Association of State Highway and Transportation) programmes, and the ACI (American Concrete Institute) and ASCE (American Society of Civil Engineers) committees have spearheaded these initiatives. These organizations have been working together to harmonize code and guideline development and have made it possible to cut the time-lines between R&D and standards implementation.

Clearly most of the initial applications have run under internal, USA programmes; i.e., in spite of the competitive nature of the USA market for most products, this sector has been, to a considerable extent, protected under the guise of R&D programmes. At present the N. American market in the FRP construction sector is being spearheaded by the pultrusion (FRP profiles) and bridge deck manufacturers who, gauging the potential for small-to-medium length bridge repair and substitution market, are aggressively seeking to introduce their products and competing seriously with standard steel and RC bridges.

It can be said therefore, that at present, the USA FRP construction industry, due to its size and the back up of a strong R&D and standardization history, is in a good position to expand into world markets.

Although European products have not lagged behind both in terms of quality and dynamics of producing companies, their small size and fragmented nature carry the risk of loosing ground —both in its own and worldwide market— to competition from the USA. To add to this scenario, the large R&D programmes in this field in the USA have resulted in a substantial brain-drain of the most expert researchers from Europe; attracted by the potential of implementing their applications into the real world and the possibility of more coherent, and larger, R&D budgets, has driven many EU researchers to the USA. In order to attract these researchers back home, the EU will need to divert resources to finance Private-Public-Partnerships tailored to EU needs

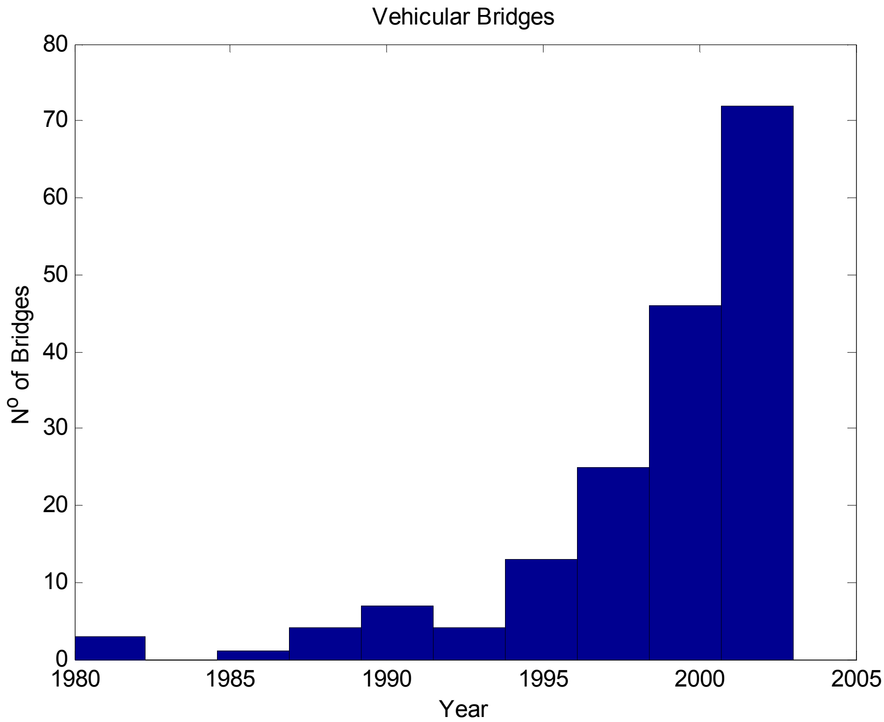

Figure 2 Evolution of number of, world-wide, vehicular bridge applications 1980-2003

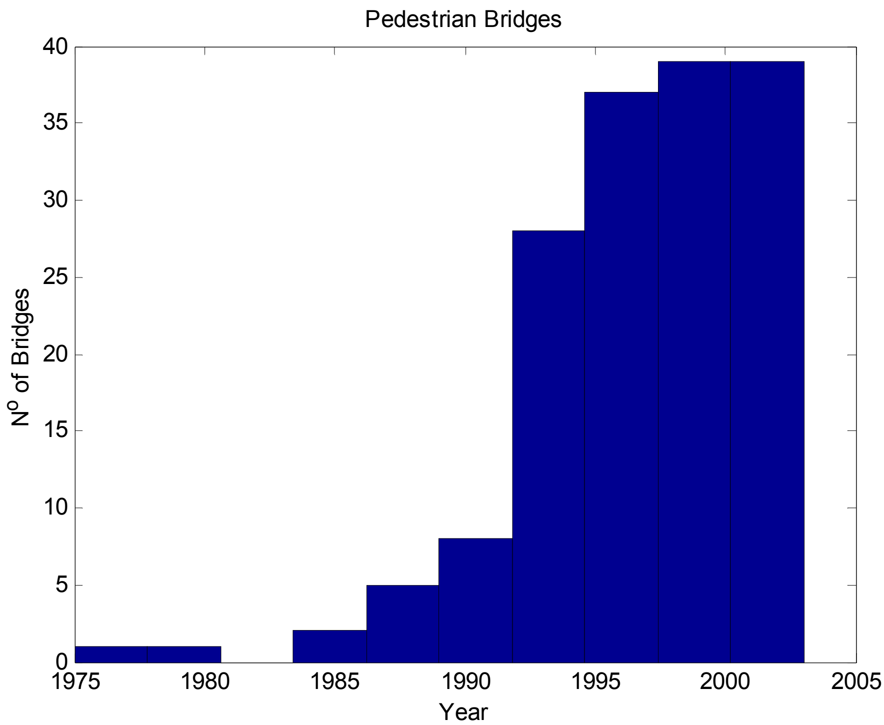

Figure 3 Evolution of number of, world-wide, pedestrian bridge applications 1975-2003.

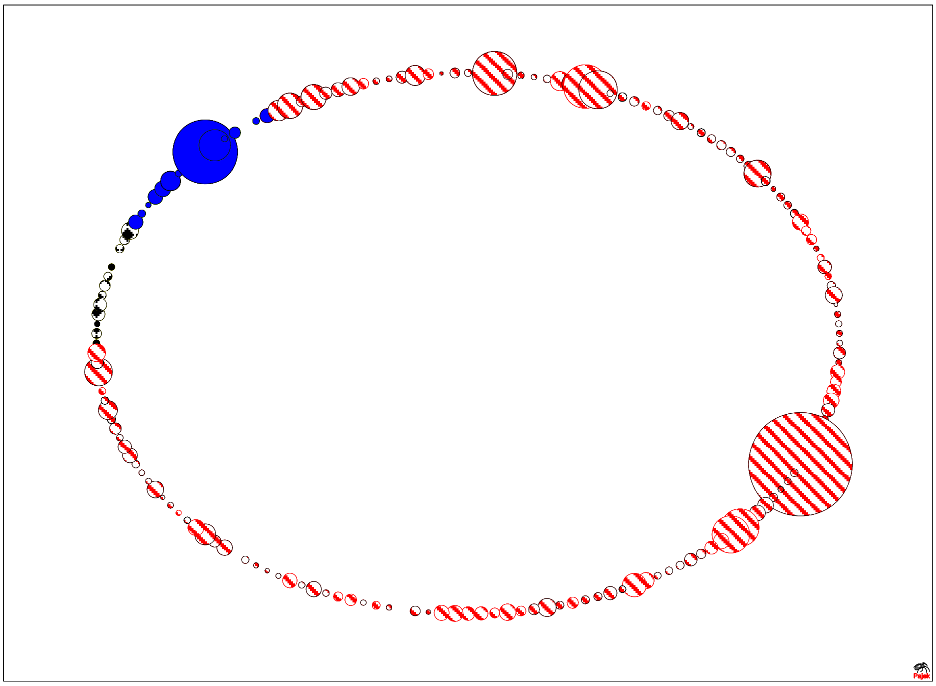

Figure 4 FRP vehicular bridge applications by regional sector: N. America (red lines), EU and EFTA (blue solid), Asia and Oceania (black hatch). Size of disk corresponds to length of bridge with the diameter of the largest corresponding to 2250 m.

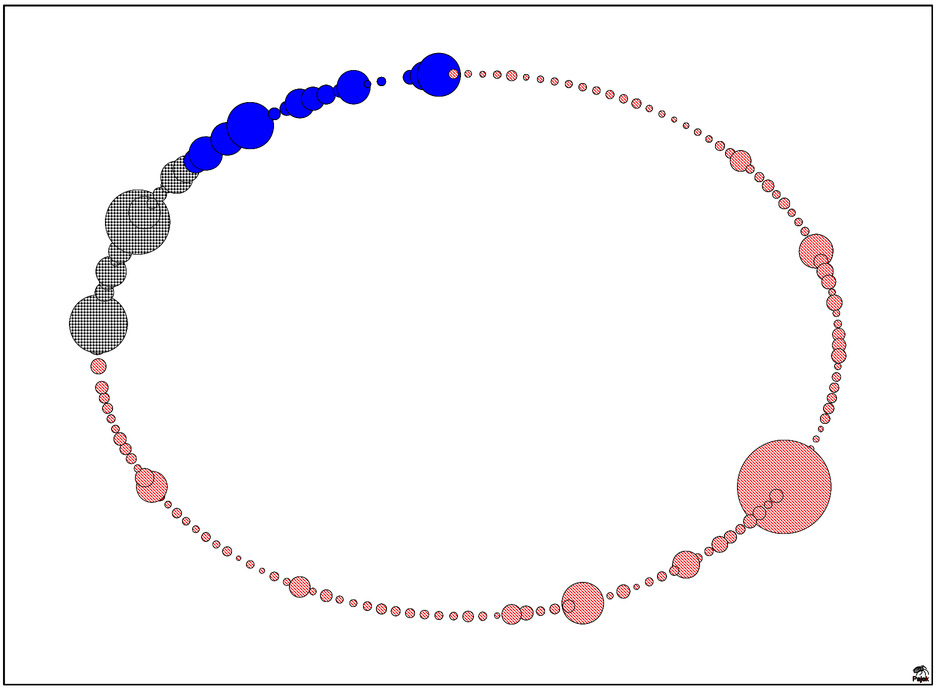

Figure 5 FRP Pedestrian bridge applications by regional sector: America (red lines), EU and EFTA (blue solid), Asia and Oceania (black hatch). Size of disk corresponds to length of bridge with the diameter of the largest corresponding to 384 m.

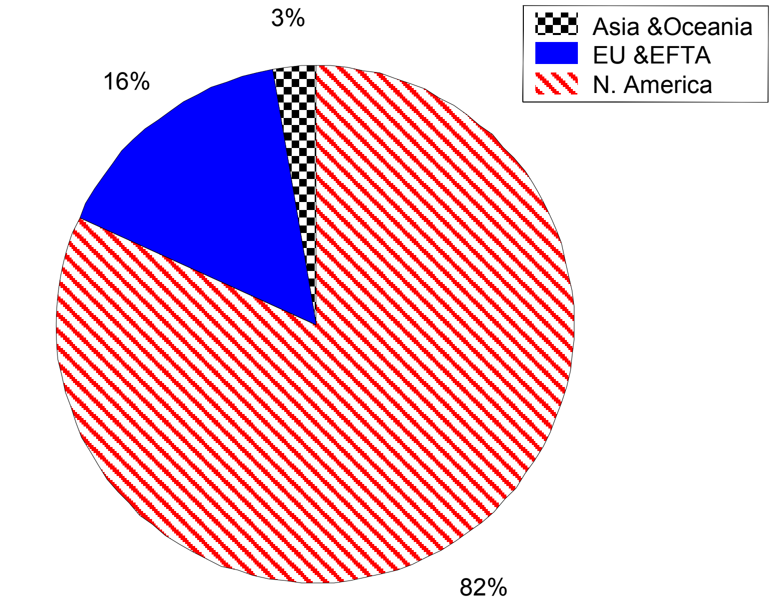

Figure 6 Total lengths of vehicular FRP bridge application use by region.

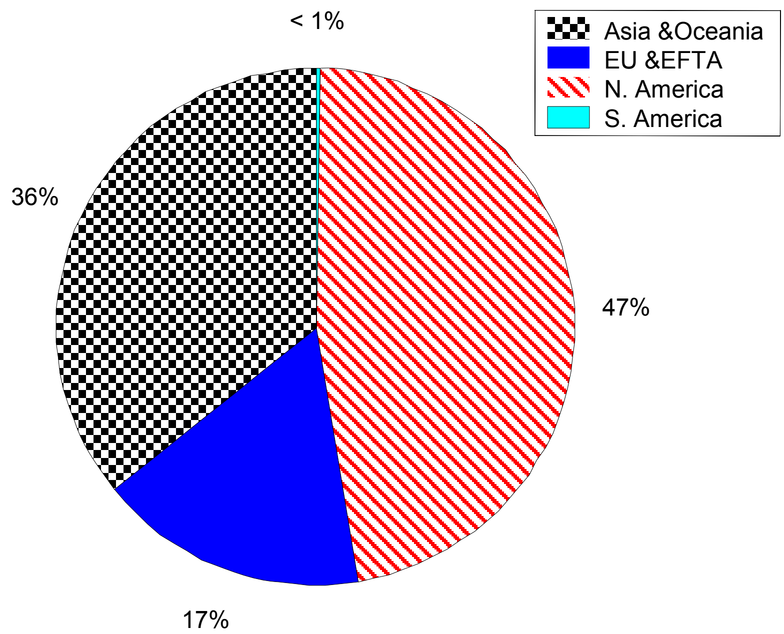

Figure 7 Total lengths of pedestrian FRP bridge applications by region.

4.3 Safety Issues

It was stated above, how the number of structural applications for FRPs has grown considerably in a number of civil engineering fields. This growth was primarily driven by applications for retrofit and repair of ageing RC bridges, where FRPs are now being considered as the primary load bearing elements in bridge decks and bridge super-structural elements themselves. To this effect, the catalogue of both pedestrian and vehicular bridges has been growing progressively in the period 1990-2005.

Initially, FRP applications on bridges were conceived as experimental demonstration projects conceived by consortia involving research institutions, civil or composites engineering firms and end users. In general it can be said that a high level of knowledge concerning the mechanical properties of the materials used characterizes such projects. Moreover, in view of their demonstrative nature, cost considerations were not always the prime mover. Broadly speaking, it can be said that the safety levels applied (specifically in terms of limit loads) were systematically examined both analytically and experimentally by using the most up-to date knowledge in FRP technology within a civil engineering context.

Over the past decade there has been a marked shift from R&D demonstrative projects towards market driven applications, this is particularly true in the area of repair and retrofit of RC structures. A plethora of companies in the construction sector, particularly those involved in the specialized niche markets providing specialized grouts for repair and refurbishment, have latched onto FRPs as a vehicle to promote their services to end-users who associate composite materials with high-tech engineering. Quite often the end-user is given no assurances —other than in-house design procedures, usually purporting to be based on proprietary technology— as to the certification of products and kits sold to them. This situation has resulted in a multitude of design manuals, practical recommendations and FRP products that are not immediately comparable and which make the valuation and selection process for the users all the more difficult.

A more appropriate approach for innovative products which could result in proprietary technology, and one which is consistent with the Construction Products Directive, is to confirm the technical validity of said products following the ETA route, which is precisely there to allow an innovative product to be assessed by an approval body notified by a Member State. This would allow for proprietary technology to be neutrally assessed with the necessary assurances provided by the certification in conformity to the ETA. Thus a viable mechanism exists but, as yet has not been fully exploited due to lack, amongst other factors, of any harmonized design code in this area at present.

This lack of standardization leaves opportunities for deficient FRP products and services to slip through the usual, prescriptive, quality assurance processes expected in the civil engineering construction sector. It is possible that an unregulated FRP market, currently characterized by the potential to deliver wide profit margins, could result in the implementation of sub-standard applications that, one day, may result in catastrophic failures. FRP codes are essential to limit the number of structural failures that arise from avoidable negligence resulting from bad design or construction practice due to the lack of a harmonized standard.

When failures in such structures occur, it is important to distinguish when they result from the acceptable risk associated with any design code—where safety comes before profit— rather than those resulting from an unregulated market free-for-all, where profit comes before safety.

4.4 Procurement versus Performance and Prescriptive Standards

At present, the aeronautical industry is the largest user of structural composites based on carbon fibers. This industry (similarly to the military industry) exercises a stringent quality control and assurance (QA/QC) via procurement-regulated supply. This means that in order to qualify as a supplier, a FRP manufacturer must obtain certification for the constituents and the fabrication process and nothing can be altered without undertaking a rigorous and expensive re-qualification. The construction industry cannot operate in this fashion as it deals with commodity products where the acquisition process is based on competitive bids. Therefore, in order to ensure a minimum level of safety for the public, there is an urgent need for prescriptive- and/or performance-based regulations in terms of design guide as well as materials and construction specifications. Moreover, as it will be safety related products, the products will have to undergo high levels of attestation of conformity

As FRP composites enter the construction industry and become conventional materials, their use appears to be more easily regulated, at least initially, by prescriptive-based standards and specifications. They are easier to write and historically more common for emerging technologies. The problem with this type of code is that innovation and creativity are negatively impacted. This is very counter productive in the case of FRP technology, because its most valuable feature is its inherent flexibility in manufacturing and design. The code writing authorities will have to strike a balance between the need of ensuring safety and, at the same time, stimulating innovative solutions.

5 Potential Benefits of Having a Code and Detriments in its Absence

In the sections above the growth of the FRP in the construction sector was analysed. The conclusions highlight both the potential for continuing growth and the preparedness of the USA market to overtake the European industry.

In the absence of European norms in this area, it is possible that USA producers will use their proven expertise and consolidated standardisation status to compete in the European market.

Just as notable though, is the potential for expansion in the Asian, and, particularly, the Chinese market, which accounts for the single largest growth rate in the world. The Chinese government is currently seeking to minimise its dependence for steel in the construction sector by seeking to diversify construction solutions. Recently, an arrangement by the Beijing Municipality and a major Spanish construction company, have reached an agreement for the development of Carbon fibre FRP bridges based on the prototypes developed in collaboration with the JRC. It is important to point out here that the Chinese Authorities stressed the importance of backing up the bridge designs with appropriate construction codes.

In this sense the lack of codes could prove to be a stumbling block for the successful bid by a European company in this, currently, the largest construction market in the world. Clearly the R&D investment devoted to developing a European technology in this area runs the risk of failing in competitive world markets if it is not backed up by codes and standards.

Another threat to EU industry resulting from a lack of standardization, already referred to in the preceding sections, is the implementation of sub-standard products and designs. Catastrophic failures in such products could give the EU sector, and the FRP industry in general, undesired publicity which may benefit its immediate non-EU competitors. Clearly, the longer the FRP construction is allowed to go ahead using ad-hoc, non-standardised, technical solutions, the greater the risk of such catastrophic failures occurring. The only means to reduce this risk is the implementation of harmonised standards explicitly geared to FRPs. In view of the broad areas defined above, the benefits of a code can be resumed as follows:

- The European producers and industries will be motivated to produce construct and manufacture high quality construction products. These will not only meet the requirements of the safety Member States; but, by ensuring a high quality, will enable European industry to compete advantageously against imported products within the open, competitive, European market.
- Due to the market stagnation induced by the absence of clear guidelines, there is a tangible possibility of favouring the acquisition of European firms by extra-EU enterprises and multinationals, with subsequent loss of a leading position in the global market.
- Competitiveness of Europe with respect to USA, Japan and Canada (which already has developed its own code) would surely benefit, especially from the construction industry stand point.
- The development of a new code would give an important thrust to theoretical and experimental researches in this field throughout Europe.
- The development of a Eurocode would comply with pressing needs and exigencies of diverse nature, originating from industries, end users and designers.

Other salient points associated with the lack of an EU-wide FRP code can be resumed as follows:

- Currently, the number of applications in the professional world and from the construction industry is steadily increasing, so it is expected that the gap between the application and codes is bound to widen.
- Different codes are being developed Europe-wide, so it is expected that in the future there will be difficulties in producing a new code that harmonizes with all of them.
- New structural systems made from FRP are being developed, patented and applied without any control over their correctness and appropriateness (actually, a few hundred strengthening interventions already exist that fall in this category).
- Harmonization is strongly needed of the various existing approaches for design, and elimination should be sought of the confusion generated by the many documents produced by private firms to promote their products.
- Unification of testing procedures (for materials, elements, etc.) should be pursued.
- FRP already has recognition as a structural material in Part 3 of Eurocode 8 where it is considered as a strengthening material for seismic upgrading. A new ‘horizontal’ FRP code would serve not just Eurocode 8, but the remaining Eurocode set.
- The need for a new unified code is felt throughout Europe (trans-nationality).
- Through numerous letters of interest, European industries have clearly demonstrated a keen interest in economically supporting the activities related to the development of a new code.
- In the initial stage, the preparation of the code could benefit from the experience and the work carried out by *fib* Task Group 9.3, which has developed the twice-reprinted Bulletin number 14.

6 Planning and Consultations

On the basis of a go-ahead for a new code, the planning and consultation stage will be conducted by the key stakeholders under the auspices of the European Commission, namely DG ENTREPRISE. As was highlighted in Section 3 (Interested Parties) this will concern on the one hand the key EU-wide organizations representing the industrial parties; on the other, the regulatory authorities from member states as well as CEN, EOTA and research institutions with a proven record in pre-normative research and code development.

The industrial organizations will endorse the project based on the argument that the new code and guidelines to be developed are motivated by the pressing needs of EU competitiveness in this area. In the first instance the construction sector organizations will be expected to draw up a programme which will identify the first wave of construction works and their associated economic and life-cycle analysis for which their industry sees the most pressing need. This will serve to identify the generic structural elements, their potential application rate as a percentile of the whole market, and the perspectives for tonnages of raw materials. These data will then be put to the Composite materials producers in order to gauge the most appropriate manufacturing methods and to compare the present day production capacity to the prospective European tonnage demand. Together this will set the background for the structures and materials that the code and guideline designers (CEN, EOTA) and pre-normative researchers will have to address.

Another important aspect of the consultation stage will consider the scope of the proposed code balanced by the cost of its development. One suggestion received by the JRC is that a compact design code (i.e. not as extensive as the concrete or steel Eurocodes) could be drafted to accommodate the prerequisites of the Construction Products Directive and be commensurate with the actual size of the FRP market. This could then set the framework for a more extensive code if the market use continues to increase.

The form, substance and financing of the studies conducted during the planning and consultation stages will be the subject of the second stage of the on-going study conducted by the JRC under the terms of the Administrative Arrangement.

7 Feasibility

By *feasibility* what is understood is the capacity to undertake the development of a new Eurocode using the currently available knowledge. Such a knowledge-base will be compiled from available EN product standards (e.g. pultruded profiles), results of pre-normative (or similar) basic research in structural elements and their durability, as well as international materials testing and products standards, such as ISO, that are acceptable directly by the Eurocode family of codes.

The feasibility analysis follows closely from the planning and consultation stages. In this sense, the feasibility study should concentrate on those structural elements and materials that offer the highest potential for application (within a short time-scale) directly to the construction market. The feasibility will not only require the compilation of the entire available FRP-related guidelines worldwide, but will also require an extensive evaluation within the context of the available EU FRP manufacturing and production capacity. Just as the aim of the planning and consultation stages to select those structural forma and materials that most conform to the predictions of the construction market, so in the feasibility analysis, it is important to target not just the available guidelines but also the realistic production capacities of the manufacturing methods which go to producing them.

8 Strategic Plan (How to Move Forward)

The strategic plan will be drafted by the stakeholders described in the sections above. The main aspects of the plan will be as follows:

- Define the legal and economic basis (remunerated public bids and private-public partnerships) that will motivate participation in the strategic plan.
- In addition to the above: define the *stake* that each of the stakeholders will have in the development of the new code.
- Approval of strategic plan by all stakeholders and responsibility lines and management structure for all participants.
- Framing the new code within the strategic plans of CEN and EOTA.
    - Define the setting of the new code within the context of the current Eurocode set.
    - Likewise, as above, for ETAGS.
- Definition of scope of code (structures, materials and processes).
- Definition of schedule and resource requirements for conducting planning and feasibility studies.
- Dissemination of activity (including knowledge bases of FRP civil engineering applications) to individual members of professional, commercial and academic organizations.
- Techno-economic analysis (including construction and manufacturing methodologies, economic life-cycle analysis, repair and rehabilitation techniques) to be presented to DG ENTR.
- Training issues (specific programmes for both practising and future civil engineers)

For the industrial associations this will require them to pool resources form their members ensuring the participation of those that have most to gain from the new code. This will create a culture of buying-in to the project giving leeway for the individual commercial interests that are best suited to the competitive environment of the construction sector. For the national regulatory and code development authorities their role as overseers of the code development will ensure that commercial interest is bounded by the broader interest of the public at large. For the academic and research institutions, the prospect of developing a new code, within the context of appropriately funded strategic programmes, will motivate both young and experienced researchers, and the return of a sizeable minority of the scientific Diaspora currently affecting this sector in Europe.

9 Remarks

A wider consultation and feasibility analysis is foreseen (as described in the sections above) within the context of the on-going Administrative Arrangement. Within the following months it is expected that ELSA will receive responses from the ECTP and EuCIA to questionnaires sent out to their members asking them for feedback and level of commitment on the matter of the proposal discussed herein. The ELSA Unit, for its part, is also contacting its peer organizations in the academic and research environment, to gauge their interest, suggestions and commitment to participate in the preparatory works leading to the development of the technical documents as a basis for the proposed standard.

European Commission

EUR 22864 EN– Joint Research Centre

Title: Purpose and Justification for New Design Standards Regarding the Use of Fibre-Reinforced Polymer Composites in Civil Engineering

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Abstract

The scope of this document concerns the purpose and justification for a new Eurocode for fibre-reinforced polymer (FRP) composite materials, outlining the specific aims and reasons for standardization in this area, and the main interested parties (industry, consumers, trade, standardisation authorities and distributors) who will benefit from it.

In order to promote the realisation of construction works with FRP materials, and the perceived immediacy for a design code pertinent to them, this proposal considers the timeliness of the Eurocode in view of the available technology.

In view of the importance of the construction industry in the European market, this proposal examines the potential benefits of the new Eurocode, or conversely, the detriments were it not to be implemented. Moreover, given the number of construction works currently using FRP materials without the availability of a standard design code, this proposal considers the urgency with which it is required.

Finally, it provides a tentative proposal for the consultation, feasibility analysis and initiation strategies

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